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Research studies on instructional procedures in elementary school science are reviewed for the period 1960-68. Proposed is a model of an instructional sequence which is used as a reference point for analyzing the studies. Areas discussed include audiovisual aids, comparative studies, ability grouping, use of reading materials, programed instruction, individualized instruction, concept development, critical thinking, problem solving, and inquiry in science. Some 15 conclusions are stated which emerge from the studies reviewed. A 132-item bibliography is included. (GR)

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An Analysis of Research

Related to Instructional Procedures In Elementary School Science

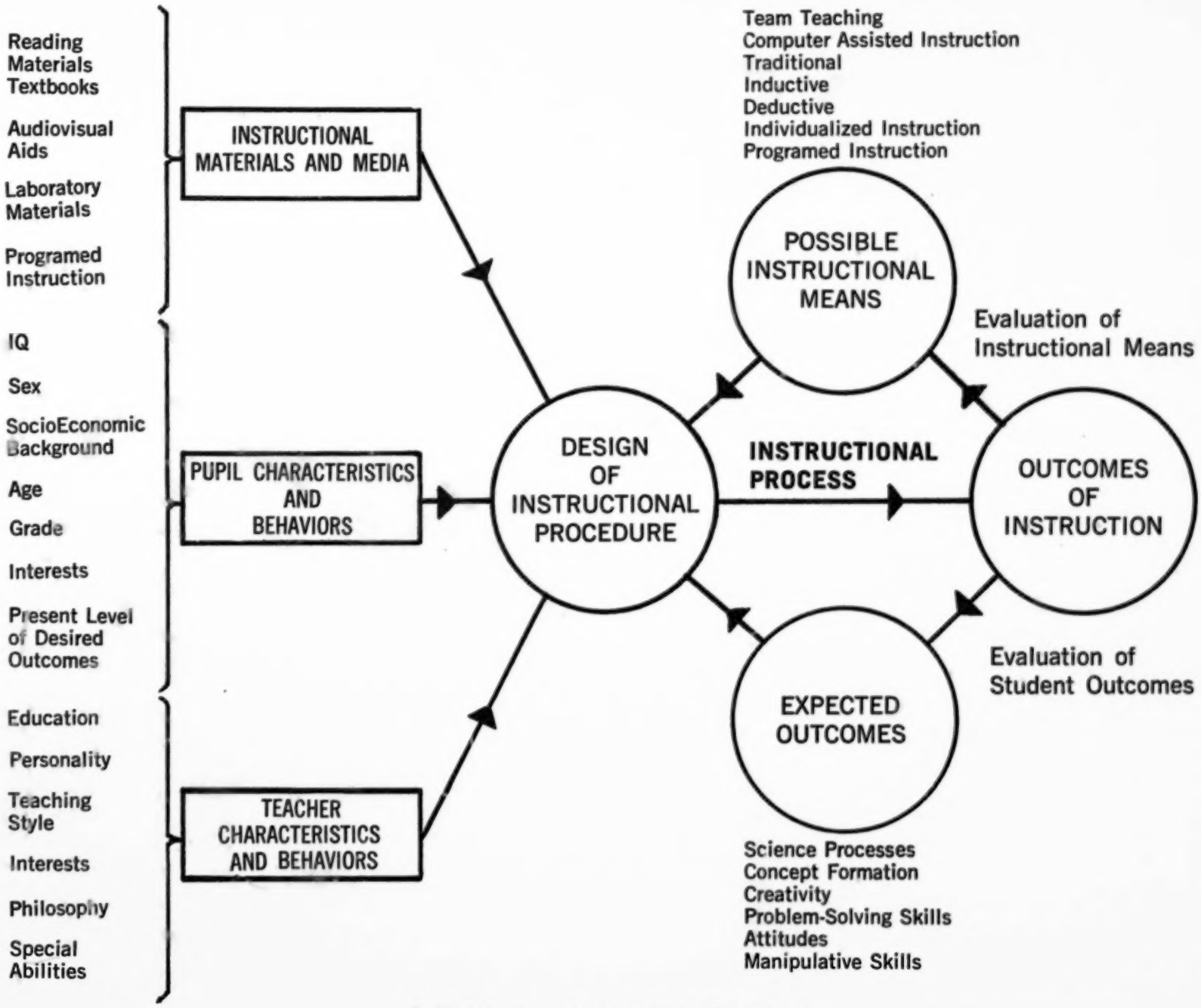
THE Educational Resources Information Center (ERIC) comprises a network of decentralized clearinghouses in various locations throughout the United States. Each center focuses on a specific area of education and organizes its own program of acquiring, abstracting, indexing, storing, retrieving, and evaluating significant materials in the individual fields of interest. The clearinghouse for science education is located at Ohio State University in Columbus, Ohio. Since July 1966, a limited number of documents selected and catalogued by each clearinghouse have been announced in the monthly publication of ERIC, *Research in Education*. The science education clearinghouse of ERIC is of particular interest to elementary teachers since it is designed to help teachers keep informed of new instructional techniques and materials. For further information about the center and its services, teachers are encouraged to write to the authors. This article is the second one published in *S&C* designed to acquaint our readers with research being done in elementary school science.

THERE is little doubt that science has a place in the elementary school. This position has become more firmly established in recent years; however, what that place is seems not at all clear from the research studies which have been undertaken and are reviewed in this article. If science were removed from the elementary school curriculum, it is difficult to know what would be lost because there is a lack of adequate and appropriate research which examines the actual outcomes of science instruction. Instructional procedures selected for study by researchers seem to be chosen on the basis of whim or tradition rather than from a firmly established proposition that if a certain procedure is used then definite, specifiable, and desirable outcomes will be the end result.

The authors found it necessary, while reviewing the available research literature, to sketch a working model of the complete instructional process. It was then possible to match any given research study to that part of the model being investigated, and also relate its relevance to the total instructional picture. The reviewers are aware that this practice may impose a model on a researcher to which he may not subscribe. However, very few researchers established clearly which part of the instructional process they were attempting to investigate.

The fact that there seemed to be no common model among researchers as to what constitutes instruction made it difficult for the authors to draw together a number of studies and make common generalizations regarding them. Also, there was some confusion over terminology used by investigators to describe the instructional process, and there seems to be an urgent need for a common set of terms to describe both the instructional procedure and the expected outcomes of the instructional sequence. More basically perhaps, what is required is a viable instructional theory which can act as a common springboard for research; however, until this is achieved, a common set of terms based on a functional model of instruction would help greatly in bringing order to the field of educational research.

Science is taught in the elementary school presumably because it is expected to bring about pupil growth in the cognitive, affective, and psychomotor domains of knowledge—a growth not as easily achieved through another content area. Evidence of such growth can only be observed through desirable changes in pupil behavior—so before embarking on any instructional sequence, it should be possible to define what behavior changes to expect, and after the sequence, be able to measure if they occur. Any learning experience will provide unexpected and unmeasurable (at least for the present) changes in behavior; however, this is not sufficient reason to neglect all attempts



A Model of an Instructional Sequence*

at measuring expected pupil growth. Only rarely did the authors review studies which paid close attention to the dual problems of devising a procedure to produce certain specified outcomes, and then measuring to see whether the outcomes have been attained.

The working model of the instructional process against which the research studies were reviewed is shown in the accompanying chart. This chart is provided for the reader not because it is complete, nor even completely accurate, but because it was useful to the reviewers for pinpointing those aspects of instruction being researched, and helped them in deciding quickly whether the researcher had accounted for all the variables which could influence instruction and its outcomes.

The boxes on the left represent three important inputs which help decide which instructional procedure should be used. The instructional materials and media available, the characteristics of the pupils to be taught, and the personalities and other traits of the teachers are relatively constant factors in any given instructional situation. The two major variables are the possible instructional means and the expected outcomes. For example, if an outcome like creativity is desired, then it is unlikely that a conventional class—teacher-didactic situation—will produce the greatest gains. So, if expected outcomes are defined, they help determine the instructional procedure to be used within the constraints imposed by the characteristics and behaviors of both the teachers and pupils, and the instructional materials and media available.

Once an instructional procedure has been established and used to teach children, then certain outcomes are attained. These outcomes are evaluated, usually by some form of testing, against the outcomes expected when the procedure was designed. How closely the outcomes attained match the outcomes expected will give some indication of what changes are needed in the instructional procedure chosen.

In reviewing the research, the model was used in the

* At the end of any instructional sequence, the inputs, e.g., student or teacher characteristics and behaviors have been changed by the sequence and this will have to be taken into account when planning the next.

following way: There are four major sets of variables which may affect the outcomes of instruction—the instructional materials and media used, pupil characteristics and behaviors, teacher characteristics and behaviors, and the instructional means chosen. To know whether a particular instructional means (e.g., a problem-solving method) does produce the change in behavior indicating the desired outcome, then all the other factors must be held constant or allowed for in the research design before one can be reasonably certain that it was the instruction and not some other variable which produced the change. Any one of the components of each of the four areas could be investigated in this way. If, in a comparative study, one wanted to investigate the effect of pupil socioeconomic background on the outcomes of a particular instructional sequence, then all *other* student characteristics must be controlled, the teachers should have essentially the same characteristics and philosophies, and the materials used must be identical in all classes taught the method.

This complex arrangement of variables which can develop may help the elementary school teacher understand some of the problems of research in this area. In fairness, it must be pointed out that most researchers coped very well with all the variables. Randomization of pupil populations is a much more effective way of controlling student characteristics than identifying matched pairs, and was used in many studies. Major objections to many of the designs were in terms of teacher characteristics not being fully controlled, and the instructional sequence not used for a long enough time in many cases for marked gains to be noted. No doubt these weaknesses are partly due to the problem that much of the research reviewed was done for doctoral dissertation purposes, where the rush to "get finished" was a contributing factor.

The reviewers found it necessary to place arbitrary limits on the studies reviewed so that the field could be contained in manageable form. In general, only studies reported after 1960 were examined, and from these only those studies which attempted some objective evaluation of the outcomes of an instructional sequence are discussed in detail in this article. Likewise, studies which were designed to test various aspects of learning theory, although they may have used a novel instructional procedure to do this, were ignored. Learning theory forms an important basis for designing an instructional procedure, but it has only an indirect effect on classroom teaching.

A number of classification systems could have been chosen in terms of the model to systematize the widely divergent research studies encountered. Four variables seemed to stand out, namely: the instructional procedure used, the outcomes evaluated, the subject matter taught, and the grade level of instruction. In practice only the first two remained relevant. The choice of subject matter in most cases seemed quite arbitrary, and when grade level was considered, more than 95 percent of the studies involved grades 4-6 and the bulk of this attention was directed at grade 6.

The studies are reviewed in terms of whether they focused on the instructional procedure, e.g., inductive or deductive, individualized instruction, programed instruction, or whether the studies focused on outcomes, e.g., development of concepts, attitudes, problem-solving skills, creativity, or understanding content. It was surprising to find the outcome category "development of psychomotor skills" void, since it might be expected that this would be an important area to be developed in elementary school science. No information was obtained concerning what manipulative skills in science can be developed in elementary school children, nor whether a hierarchy of such skills can be identified. This area requires much more basic research.

A number of "status" studies were identified. School systems were surveyed for procedures used, e.g., Snoble (113)[1] and Swan (120), or wider surveys of national practices were made, e.g., those by McCloskey (79), Moorehead (83), Smith and Cooper (111), Blackwood (13), Stokes (116), and Melis (81).

These status studies are in a sense reviews themselves and provide sound statements of the position in the areas mentioned. They are not discussed further in this article, but are cited as useful sources for the interested reader.

Only one study was identified which attempted evaluation of one of the newer course improvement projects in elementary science. This study was undertaken by Walbesser, *et al* (126) and the American Association for the Advancement of Science in their comprehensive study of *Science—A Process Approach*. An evaluation model was posed which described expected learner behaviors and established what might be accepted as evidence of learner accomplishment. Evaluation in these terms allows for objective comparisons of courses, gives objective evidence that learning has occurred, and makes independent replication of the findings possible.

The behavioral objectives of each instructional sequence were clearly identified, and they were evaluated by determining the percentage of pupils acquiring a certain standard percentage of specified behaviors, and comparing this to an established level of expectation. From this information, feedback to improve the instructional sequence was constantly available. For example, an arbitrary 90/90 (90 percent of students acquire 90 percent of the prescribed behaviors) was chosen as the standard. If the standard attained by pupils were lower than this, then modifications were made to the instructional sequence.

Specific findings of the evaluation were too varied and far reaching to be described in a review of this nature; however, it is the model provided by the evaluation, rather than the results which are important. Much has been said and written about the efficacy of stating objectives in behavioral terms. This study gives concrete evidence that this is so.

Comparative Studies: Traditional vs. Nontraditional

In this section are reviewed those studies which compared outcomes obtained when the same body of content is taught by two methods. A "conventional" or "traditional" method was the usual standard of comparison, although what researchers meant by these terms was not always clear. Methods investigated included "inductive," "directed self-discovery," a "field method," "democratic," and "problem solving." It was in this area of comparison studies that the reviewers had the most concern regarding the research design. It is extremely difficult in such circumstances to control all the variables which may affect instruction. A study by Brudzynski (16) illustrates this point. He compared an inductive method where pupils learned concepts by "directed self-discovery" in a pupil-centered atmosphere to a "lecture-demonstration" teacher-centered one. The "inductive" method favored above-average students while the "lecture-demonstration" method

[1] See references.

favored average and below average students in the fifth- and sixth-grade population studied. These differences need not be ascribed to the particular instructional method. Teacher expectation may have been far more important. The less-able students may not be "expected" by the teacher, perhaps subconsciously, to perform as well in a self-directed situation. He may act in the classroom accordingly and this subconscious expectation could affect the outcomes of the students more than the instructional procedure used.

Anklam (5) identified the teachers who liked to use "democratic" instructional methods and those who preferred a more "autocratic" approach. No significant differences in achievement motivation existed between the groups of pupils taught in each of these environments. This finding points clearly to the importance of teacher characteristics and behaviors to the whole instructional procedure, and the danger of imposing a particular procedure upon teachers who do not have the personal characteristics to teach it. In this study, the teachers investigated had adopted a style of teaching which suited them. Even though the simplicity of the democratic-autocratic dichotomy may be doubted, the study did show that teachers performing within a frame of reference which they have built for themselves, motivated students equally. What is needed is research into determining instructional procedures which suit different personality types, rather than research directed to finding one procedure "best" for all teachers.

Other studies where no significant differences were found between methods used included Gerne (51) who compared a traditional textbook method with a method utilizing a specially designed board to teach electricity and magnetism, and one by Bennett (10) who compared a field method with a classroom method for teaching ecology. Smith (110) compared a lecture-demonstration style of teaching carried out in a classroom to teaching in a planetarium for presenting a lesson on astronomy concepts to sixth-grade pupils. Children in the classroom achieved significantly higher than those taught in the planetarium. These studies suggest that the use of any visual aid or direct experience will not necessarily of itself produce significant outcome gains in children.

Carpenter (24) used fourth-grade pupils to compare a "textbook recitation method" with a "problem method." In effect, the textbook method included no demonstrations while the problem method was based on classroom demonstration and experimentation. Achievement of content gains were strongly in favor of the problem-solving method for teaching units on "magnetism" and "adaption of animals." This finding was even more definite for the slower learners—who were, in general, poor readers.

Pershern (91) investigated student achievement outcomes obtained by integrating industrial-arts activities with science instruction in grades 4, 5, 6. He used electricity and machines as his content vehicles and found significant gains in favor of integration for the electricity unit, but no significant differences for the machines unit. Integration seems to add an important dimension to instruction, and may prove a useful approach for further research.

It is difficult to generalize from comparison studies, however, it seems that pupil activity and pupil-performed experiments are important prerequisites to the effective learning of science concepts. Instructional procedures where the responsibility for the conceptual leap is placed upon the child, as in problem solving and inductive methods, do seem to bring about more significant achievement gains than do those methods where the teacher or the text material provides the concept. It appears that for these inductive methods to be fully effective, the teacher must have a certain teaching philosophy and a certain set of personal characteristics.

Audiovisual Aids

The bulk of the research in this area involved the use of television and movie film in the classroom. How these aids can best be used in an instructional situation, what their effect is on student achievement and attitudes, and how they can improve classroom instruction are all questions to which research has been directed. Much of the research was of the "direct-comparison" type where control of all variables is extremely difficult. Conclusions based on such studies should be viewed with some caution.

Bickel (12), Decker (36), and Skinner (109) investigated changes in attitude, achievement, and interest in children following television instruction. Bickel (12) found no significant differences in the learning outcomes of his fourth-, fifth-, and sixth-grade pupils taught science by closed-circuit television incorporating a "talk-back" facility and teacher follow-up, when compared with students taught science without the aid of television.

Skinner (109) compared two television presentations for two separate groups of fifth graders. In one presentation a problem was identified, and many questions were posed which were not answered in the lesson. In this way, it was hoped that pupils' curiosity and interest in science would be aroused. The other presentation included the same materials, but used a direct expository teaching style with very few questions. Teacher follow-up of these lessons was either a modified inquiry session where the teacher answered only pupils' questions or a typical discussion session with teacher and pupils participating fully. Skinner found that pupils who experienced the television presentation with unanswered questions, regardless of teacher follow-up, achieved significantly higher than pupils who viewed "explanation" on television.

Decker (36), like Skinner, also worked with fifth graders and followed a somewhat similar procedure. He prepared two sets of ten half-hour television programs using the same materials for each. One set stressed providing information, concepts, and generalizations while the other stressed the posing of problems. No significant differences in pupil achievement were detected, so Decker concluded that the problem-solving method was as effective as the information-giving method in teaching natural science.

These conflicting results of Skinner and Decker, where one finds a significant difference in one and no significant difference in the other, point clearly to the difficulties associated with these direct-comparison type studies. They oversimplify the learning process and do not take into account how individual student needs, interests, and abilities interact with instruction. An instructional method which may be in tune with the profile of characteristics of one group of students in the class may be out of tune with another, so any gains obtained with one group will be offset by the losses in the other, and no significant differences are detected. Research on instructional procedures must be increasingly multi-dimensional, since no one method of instruction can be considered "best" for all students.

Bornhorst and Hosford (15) investigated television instruction at the third-grade level by comparing the achievement of a group of television-taught pupils with a group

who had only classroom instruction. The television group achieved significantly higher results on tests than the control group, and it was felt that the "wonder-box" where children placed questions arising from the television lessons for future discussion was an important factor.

Allison (3) investigated the influence of three methods of using motivational films[2] on the attitudes of fourth-, fifth-, and sixth-grade students toward science, scientists, and scientific careers. He adapted the Allen attitude inventory[3] for use with these elementary school children. Allison concluded that the films did change the attitudes of the students favorably toward science, scientists, and scientific careers, and that these changes in attitude were not related to mental ability, science achievement scores, sex, science training, or the economic status of parents. This study suggests that film sequences can be devised which will effectively bring about a desired attitude change. More research in this area is needed particularly in the development and evaluation of material.

Novak (87) describes the development and use of audio-tape programed instruction for teaching first- and third-grade elementary science. Cartridge tape recorders and projectors with simple "on-off" switches were used. Some of the problems associated with setting up such a program included vocabulary difficulty, pace of audio instruction, difficulty of task to be performed, density of information to be presented, inadequacies of filmloops, and unexpected distractions. Four to eight revisions of each program sequence were necessary to be sure that students could proceed with very few apparent difficulties.

Evaluation of the program was highly experimental. Individual interview using loop films, display materials, and appropriate questioning was found too time consuming. Pencil and paper tests using drawings, administered orally to the whole class, were then tried. Also, several suggestions as to future possible avenues of evaluation were developed along with other ways the materials may be used. The study leaves little doubt that audio-tutorial instruction is feasible in grades one, two, and three, and should be looked on as a useful way to individualize instruction.

Programed Instruction

The role of programed instruction in the elementary school has had some attention from researchers. This is understandable since such programs encourage individual student work, and free the teacher from direct instruction to perform other tasks.

Hedges and MacDougall (61) investigated the effectiveness of teaching fourth-grade science using programed science materials and laboratory experiences. The study had three phases. In phase one, the purpose was to establish the possibility of programed instruction as a teaching method. This was done by observing students using the materials, and determining student and teacher attitudes. The information was used to revise and rewrite the programs as part of phase two of the study. The final report on the evaluative phase (phase three) has not yet come to the reviewers' attention; however, the intention was to compare innovative ways of using the materials with a more traditional approach under the headings: achievement, interest, problem-solving ability, ability to generalize, and retention. This three-phase method of determining feasibility, refining materials and methods, and evaluating student and teacher outcomes outlines a promising sequence for the development of instructional procedures.

Blank (14) investigated developing inquiry skills through programed-instruction techniques. The programs trained children to ask questions about the relative dimensions of problems before attempting to solve them. He found that the children given inquiry training asked significantly more questions (as well as a lower proportion of irrelevant ones) on oral and written criterion tests than did students in control groups. This improvement in inquiry skills was not at the expense of other achievement criteria, so it was found possible to introduce inquiry training without affecting progress in regular course work.

Dutton (41) investigated pupil achievement using programed materials on heat, light, and sound with fourth graders. He found that children did proceed at different rates and that they could perform simple science experiments with little teacher supervision. Pupils using the programed materials learned concepts more efficiently than did those in classes taught in a conventional way.

Crabtree (30) studied the relationships between score, time, IQ, and reading level for fourth-grade students by structuring programed science materials in different ways. Linear programs seemed preferable to branched versions since the same amount of material was learned in less time. Other findings were of the "no significant difference" type, although there was some evidence that multiple choice type response requires a higher reading ability than other response forms.

Taylor (122) investigated the effect of pupil behavior and characteristics and teacher attitudes on achievement when programed science materials are used at the fourth-grade level. Teacher attitudes, combinations of pupil and teacher attitudes, pupil intelligence, interest, and initial knowledge of science, along with other selected personality and performance factors all contribute significantly to pupil final achievement. The study indicates that any given set of programed science materials cannot meet the needs of all the students at any given grade level.

Individualized Instruction

Instruction may be classified as individualized if experiences are specifically designed for each individual child, taking into account such factors as background, knowledge and experience, reading level, interests, and intelligence. There have been several attempts at individualizing which have tried to allow for the individual needs of children in the instructional design.

Baum (8) prepared materials to test the feasibility of individualizing science experiences for fifth-grade pupils. He devised a series of pretests of skills and knowledge so that pupil deficiencies could be identified. Each pupil was then assigned a kit specially designed to help him acquire the skill or competency shown to be deficient on the tests. This method was found suitable for helping pupils achieve curricular goals in the area of science. Evaluation was carried out by observing pupil reactions to this instruction, and though the evaluation was subjective, the strengths of the program in terms of desired outcomes clearly emerged.

O'Toole (89) compared an individualized method with a teacher-centered approach in the teaching of science to fifth graders. He found no significant differences between

[2] "Horizons of Science." Films produced by Educational Testing Service, Princeton, New Jersey.

[3] Allen, Hugh Jr. "Attitudes of Certain High School Seniors Toward Science and Scientific Careers." Teachers College, Columbia University, New York City. 1960.

his groups in achievement, problem-solving ability, or science interest. The teacher-centered program stressing problem solving as a major objective was more effective in developing the ability to identify valid conclusions while the individualized program was more effective in developing the ability to recognize hypotheses and problems.

It is likely that group methods of instruction will develop some outcomes more effectively than individualized methods, while other outcomes will develop more effectively in an individualized situation. This study was the only one which attempted to identify what some of these outcome differences might be.

Schiller (102) used activity booklets and data sheets to individualize instruction for sixth-grade pupils. The materials were designed to give children an opportunity to complete some science experiments and other activities which were in addition to the formal instructional program. Much of the evaluation was subjective, but students were eager to participate in the activities and seemed to gain from them.

Other attempts at individualizing instruction were undertaken by LaCava (69) who used the tape recorder as an aid in individualizing, Carter (25) who developed a science experience center, and Lipson (74) who developed an individualized program by coordinating audio-tapes to simple science kits. These studies, in general, support the contention that individualizing instruction is possible and educationally desirable at the elementary level. To date, however, evaluation has been highly subjective.

A more rigorous evaluation of an individualized program was undertaken by Gleason (54). He measured pupil growth in areas of general science knowledge, liking for science, and learning to generalize. Although he found no specific advantages in favor of individualized self-study activity in science, pupils learned as much content by themselves as they did when taught by a teacher.

An important project related to individualizing instruction is the Oakleaf Project for Individually Prescribed Instruction discussed by Lindvall and Bolvin (72). Here, the Oakleaf Elementary School is used as a laboratory for testing the feasibility of individualizing instruction, developing suitable programs, and evaluating the effects of such instruction.

Ability Grouping—Socioeconomic Status of Students

Three studies investigated the effects of socio-economic status on achievement in elementary school science. Some of the findings have clear implications for instruction.

Rowland (98) compared the science achievement of sixth-grade pupils of high socio-economic status with those of generally low status. He found that given equal intelligence and equal science background experiences, higher socio-economic status pupils show greater science achievement than do lower groups, and these differences carry over to all the various types of science achievement measured. He found that it is of great importance that lower socio-economic status pupils have opportunities to manipulate and study simple science materials, and this should precede experience with more complex types of commercial science aids. Also these students should engage in concrete science experiences before being expected to learn from reading or discussing science material.

Wagner (124) compared the responses of economically advantaged and disadvantaged sixth-grade pupils to science demonstrations. Pupil responses to the demonstrations were obtained by getting them to either write about, tell about, or construct pictorially, using predesigned plastic templates, suitable applications of the demonstrations. Advantaged pupils were significantly superior in written and oral responses, but no differences were detected in the construction responses. This finding suggests that disadvantaged pupils understand and can communicate their understandings of science concepts when placed in situations requiring limited language response.

Becker (9) investigated the achievement of gifted sixth-grade students when segregated from, partly segregated from, or homogeneously mixed with students of lower ability. No significant differences were detected between the groups, and no special advantages accrued when gifted children were placed in special groups. Unfortunately, the description of the design of the study did not mention some important aspects, one of which was the length of time students were placed in these various arrangements. This time factor is likely to be highly significant in such a study.

These studies point to the great importance which must be placed on student characteristics in the design of instructional procedures. Selecting one factor, e.g., ability, from the whole range of factors which influence learning, and then separating instructional groups on the basis of it, is unlikely to significantly improve student outcomes. The factors involved in determining the outcomes of instruction are much more subtle than this.

Use of Reading Materials

Little research was detected on investigating ways reading materials may be used in an instructional situation. Some very interesting studies, however, were identified.

Fryback (46) evaluated some elementary science curriculum materials which had been written to accommodate five different reading levels in a fifth-grade class. Other variables in the design included whether the students performed experiments or not, and the extent of class discussion. He found that the provision for different reading ability levels and class discussion did not show any significant influence on achievement. Only when pupils worked experiments were significant achievement gains noted. The provision of different reading levels and class discussion may have a motivational effect for later work and may affect other outcomes, but these data indicate that the provision of experiments to be performed individually by pupils is important.

Bennett and Clodfelter (11) investigated student learning of earth-science concepts when the science unit was integrated within the reading program of second-grade children. For the integration, a "word-analysis" approach was used. In this method, the child was given a basic list of words to be used in the new resource unit on earth science, and then introduced to their meanings before presentation of the unit. The "word-analysis" group showed greater achievement gains than the control groups where the science was taught in the traditional way. The study demonstrated that certain earth-science concepts can be learned at the second-grade level.

Williams (128) rewrote sixth-grade science materials to a third-grade level of readability, and used them with his sixth-grade pupils. Gains in reading speed and comprehension seemed to occur when the materials were used, but the duration of the study was far too short for differences in learning outcomes to be evaluated.

Research in the area of the use of reading materials is indeed thin. More and more textbooks and other materials directed to the elementary pupil are coming onto the market, yet the role of reading materials in science instruction has had little recent evaluation.

Critical Thinking

Over the period of review, only one study was identified which investigated the development of critical thinking in children. Mason (78), in a two-year study, developed materials for teaching critical thinking in grades K-6. The first year was devoted to developing materials and providing inservice seminars for the teachers who would eventually teach the course. Basic assumptions were that children should have planned experiences in science rather than incidental ones, they should have direct experience with both content and methods of science, and that experiences can be identified to give students direct training in the acquisition of scientific skills and attitudes. Evaluation of the course was subjective for grades K-3 because of the lack of suitable instruments; but, in grades 4-6 significant gains in critical thinking were made over the period of a year. The materials were particularly effective at the fifth-grade level where maximum gains were made.

It seems quite clear that instructional sequences can be devised which will develop pupils' powers of critical thinking. Only by evaluating the outcomes of the experiences can the effectiveness of these materials be assessed. There is a lack of activity in this area, particularly in grades K-3.

Process: Inquiry in Science

Much emphasis has been placed on the development of science process skills and the use of inquiry methods to develop certain cognitive abilities by the new elementary science course improvement projects. Less research has been reported in this area than might have been expected if one judges from the significant sums of money spent on developing these programs.

Kuss (95) investigated the interaction between curriculum variables and selected classroom-student characteristics using the AAAS *Science—A Process Approach* materials. He was interested in the changes in cognitive and affective behavior brought about by children using some of the strategies of science. Some of the factors investigated included problem solving, perceptual closure, verbal fluency, ideation fluency, tested intelligence, achievement, and attitudes toward science and scientists. The strategies of inquiry selected for performance evaluation after five months instruction were classifying, observing, using number relations, and recognizing space-time relations. He found limited evidence of significant grade differences between behaviors and performance in the strategies of inquiry in science, and that there was no consistent pattern of behavioral change among grades. In fact, on many of the factors investigated, grades 5 and 6 showed regressive tendencies which support the argument that there is rather slow development of science process skills beyond grade 5.

Price (93) investigated whether students who had manipulated objects and materials to gather empirical data in an elementary classroom would transfer this manipulative process behavior to a test situation outside the classroom. It was found that children rarely sought data by overt manipulative processes in the test situations, even though verbal responses to them indicated high motivational interest. Also gifted children showed no greater tendency to empirically gather data to solve problems than students in the normal range of intelligence.

Scott and Sigel (106) used grades 4-6 to investigate the effects of inquiry training in physical science on creativity and cognitive style. Pupils receiving inquiry training learned science concepts as well or better than children in conventional classes, and no significant differences were found between boys and girls. Cognitive styles did seem to be influenced by the inquiry process, and some differences in the developmental trends of cognitive styles of boys compared to girls were apparent.

More studies like the above are needed if instructional procedures are to be developed which meet the individual needs of students at each stage in their development. Inquiry methods and methods designed to have children working with the processes of science are likely to produce different outcomes than conventional procedures. These new procedures are becoming more carefully controlled, and with the development of more sensitive evaluative instruments, a clearer idea of what these differences may be is starting to emerge. Increased research on ways the new materials may be used and the outcomes obtained seems essential.

Problem Solving

A number of studies investigated problem solving in elementary children. Dyck (42), Gunnels (55), and Harris (59) all made some analysis of the problem-solving behavior of children at various grade levels. Only Schippers (103) extended what is known about problem solving into a suggested instructional sequence.

Dyck (42) wished to discover whether instruction had any effect on the length of transition period from the stage of concrete operations to more formal patterns of thought in the Piagetian developmental sequence. Gunnels (55) also investigated cognitive development based on the Piagetian stages of intuitive, concrete, and formal thought. He used an interview technique to study the development of logical judgment in science of successful and unsuccessful problem solvers in grades 4-9. In general, the Piagetian order of development was confirmed that successful problem solvers operate at a higher level of operational thought than do unsuccessful problem solvers; however, even though a child is at a given chronological age, this does not guarantee a definite level of thought process skills.

Harris (59) used sixth graders and investigated the usefulness of pupil drawings in developing a problem-solving approach to learning science concepts. He identified two kinds of problem-solving behavior: verificational and insightful, but his study concentrated on the verificational aspects which seem most often encountered in school. He made an intensive individual analysis of the problem-solving processes of eighteen children. Some of his findings are pertinent to the development of instructional procedures. He found that children do not use consistent patterns of thinking in different problem situations, and that the confidence of the child in his ability to solve problems is an important factor in his success. Also instruction in science, which includes drawing of concepts in a tangible form by the learner, was not significantly related to growth in the ability of the learner to use these concepts in problem-solving situations. A particularly sig-

nificant finding relating to the evaluation of an instructional sequence was that pencil and paper tests did not provide an adequate means for evaluating problem-solving processes in individual children.

Schippers (103) designed materials and a procedure to teach sixth graders a problem-solving instructional method using a multi-reference activity base. Three steps in the instructional process were identified: first, establish the background situation; second, understand the problem; and third, work out a solution. Supervision and the use of illustrative lessons were found important if inexperienced teachers were to use the method effectively. Evaluation of student outcomes was largely subjective.

Creativity

Only two studies were identified which made an attempt to develop materials and procedures for encouraging creativity and creative thinking in students.

DeRoche (37) used creative exercises with sixth-grade pupils to see if these produced any gains in creative thinking and achievement not seen in classes doing more traditional work. The experimental group had creative exercises in 26 space science lessons and four "brain-storming" sessions, while control classes either had 30 space science lessons without the exercises or no space science instruction at all. The *Minnesota Tests of Creative Thinking* and specially prepared content achievement tests were used to evaluate outcomes. For high intelligence students, the experimental method was significantly superior to the control in developing creative factors like verbal fluency, flexibility, originality, and elaboration. This trend was less marked for average and low ability students. No significant differences on the achievement tests were found between the "creative" group and the "traditional" group taught space science.

Tating (121) studied ways of developing creative thinking in elementary school science. Creative thinking was defined operationally as divergent and original thinking measured in terms of questions asked and hypotheses given. More divergent responses were obtained with the trained groups than with the control, but the number of divergent responses decreased if pupils were given instructions to be original. Tating "primed" creative thinking by getting pupils to write down as many questions as they could about a particular demonstration, which, if given a "yes-no" answer by the teacher, would help the child understand why a given event occurred. Another method of priming used was to get students to write down a number of words in response to a given word.

Although the asking of questions could be primed, the development of hypotheses was not as responsive to training. The formulation of hypotheses in science is a highly complicated mental process, and the formation of an original hypothesis probably requires more time than is needed to think of questions.

The evidence is mounting that creative exercises can be designed to increase creative responses in children without any losses in content achievement. Teachers are constantly being urged to teach science creatively, and more research needs to be done to estimate the effectiveness of various forms of instruction.

Concept Development

Many of the studies in this area were concerned with concept development as part of research into learning theory, rather than evaluating different instructional procedures for their efficiency in developing concepts.

Voelker (123) gives an example of pertinent research on the development of concepts within the field of science education. He compared two instructional methods for teaching the concepts of physical and chemical change in grades 2-6. Using essentially similar lesson procedures and materials in both cases, he found that formulation and statement by the teacher of the generalization to be learned was not superior to a procedure in which the pupil individually formulated the generalization concerning physical and chemical change. An interesting sidelight of the study was that although sixth-grade pupils were significantly better verbalizers of the concepts, if the criterion of understanding was simply to classify observed phenomena, no significant differences could be detected among grades 2-6. In this study, where teaching method and materials were carefully controlled, there did not seem to be any significant advantages of an "inductive-discovery" approach over a "deductive" one on the outcomes selected. Unfortunately, the concept of physical and chemical change appeared rather difficult except for pupils in grade 6.

Salstrom (100) compared concepts learned by sixth-grade pupils in two types of guided discovery lessons. The same experimental lessons were presented as a science game to each of his groups. Following this, one group had an oral inquiry session while the other received a battery of cards which on one side had printed questions a pupil might ask in an inquiry session and on the other, the answers to those questions were printed. In the card group, each pupil could draw only cards that would yield information needed to solve the problem. They were then ordered by the pupil to give a solution to the problem posed in the lesson. The card treatment group showed greater gains in concept development than the oral inquiry group, supporting the contention that more guidance than can be given each pupil in an oral inquiry session helps concept development.

Three studies were directed at finding the relationship between the child's level of maturity and the understanding of a particular concept. Carey (21) investigated the particle nature of matter in grades 2-5, Haddad (56) investigated the concept of relativity in grades 4-8, and Helgeson (62) investigated the concept of force. Maturity studies like these are extremely useful in helping course developers decide the level to which a particular concept may be unfolded with pupils at a particular stage in development. The studies suggested that there was almost as much variation in maturity within a grade level as there was between grade levels. These data question the grouping of children by grades if the aim is to provide a group of children at the same stage of mental development.

Kolb (66) investigated integrating mathematics and science instruction with fifth-grade pupils to determine if such integration would facilitate the acquisition of quantitative science behaviors. He used *Science—A Process Approach* materials and found that such integration with mathematics did significantly increase achievement. Integration seems a promising way to reduce the time spent in developing concepts which have elements common to both mathematics and science, and this aspect should be pursued further.

Ziegler (132) investigated the use of mechanical models in teaching theoretical concepts regarding the particle nature of matter to pupils in grades 2-6. They found that children who had not previously learned to use such a

model could learn to do so with suitable instruction, and those who had some knowledge of such models improved their ability to use them. These concrete experiences with mechanical models helped pupils form theoretical concepts to explain expansion, contraction, change of phase, and mixtures by the time they completed grade 4.

Studies like this and those of Carey (21), Haddad (56), Voelker (123), and Helgeson (62) should be extended into other concept areas so that a more complete picture of the concepts which may be developed at any given level may emerge. From this, suitable instructional procedures using mechanical models and other devices can be developed. Until this is done, courses of instruction in elementary schools will be based on subjective opinion and feeling about what can be accomplished at any given grade level or stage of development, rather than on a soundly researched experimental base.

Summary and Conclusions

Reviewing the available research into the outcomes of instruction in elementary science has revealed a number of areas where little in the way of a planned attack on the problems has been initiated. Such areas include the development of psychomotor skills, critical thinking skills, creativity, and work in the affective domain on the development of attitudes toward science and scientists. Only in the field of understanding concepts can one see steady progress being made.

The tentative nature of the findings of much educational research and the massive qualifications which surround any generalizations made by researchers often appear confusing to the classroom teacher. The feeling is sometimes expressed that research "has nothing to say to the classroom teacher." In light of this, the reviewers have decided to outline a number of tentative conclusions which seem to emerge from the research reviewed. They are stated without qualification so that they may be readily grasped by teachers. The purists may assume that they are surrounded by the usual modifiers demanded by the idiosyncrasies of educational research.

1. **Instructional procedures, whether in the classroom or in the research situation, should be based on some clearly defined model of what constitutes the instructional process.** The major criteria for such a model should be that it is useful in helping understand the components of instruction and that the instruction develops desired behavior changes in pupils.
2. **For teachers skilled in handling them, problem-solving or inductive methods or instructional procedures designed to improve creativity can bring about gains in outcome areas which are greater than if more traditional approaches are used.** This is not achieved at the expense of knowledge of content.
3. **Audiovisual aids and reading materials should be carefully integrated into the instructional sequence for a definite instructional purpose, otherwise little effect on achievement outcomes will be noted.**
4. **Pupil activity and pupil performed experiments are important prerequisites for the effective learning of science concepts.** This seems true for all levels of ability.
5. **Instructional procedures can be devised to bring about specific outcomes, provided these outcomes are clearly defined.** Both problem-solving skills and creativity can be developed.
6. **Individualized instruction is a satisfactory alternative to total class instruction.** Even very young children can work alone on preplanned experiences using quite sophisticated aids with minimal teacher help.
7. **Elementary children can learn by using programed-instruction materials.** Outcomes from these are enhanced if they are integrated with laboratory experiences.
8. **Each child should have the opportunity to develop science concepts and process skills in both individual and group situations.** The outcomes of one kind of instruction will complement rather than parallel the other.
9. **Verbalization of a concept is the last step in a child's understanding of it.** He can demonstrate aspects of his understanding in concrete situations long before he can verbalize them.
10. **Any given class in elementary school is likely to contain children who are in at least two stages of cognitive development—that of concrete operations and formal thought.** These two groups require quite different instructional strategies.
11. **Ability grouping has little effect on the achievement of high ability students.** Other student characteristics are just as significant as intelligence in the learning process.
12. **Educationally disadvantaged students can communicate their understanding of science concepts if the response mode is by a means other than language; e.g., pictorial representation.**
13. **Integration of mathematics and science saves time.** Where common concepts are being developed, achievement in both areas seems to be enhanced.
14. **Educationally disadvantaged children need even greater recourse to simple materials and individual experiments if they are to develop the desired science concepts to the level of other children.**
15. **Teachers should decide on instructional procedures which suit their own personal characteristics and philosophy.** Modification of firmly established patterns of teaching can only occur if there is a corresponding modification of personal characteristics and behaviors.

These conclusions are given in this way so that the classroom teacher may be encouraged to try something new or do something different and the educational researcher to assemble evidence either to support or reject them. If both these aims are met, then this review may have sparked some improvement both in classroom instruction per se, and in its enigmatic research.

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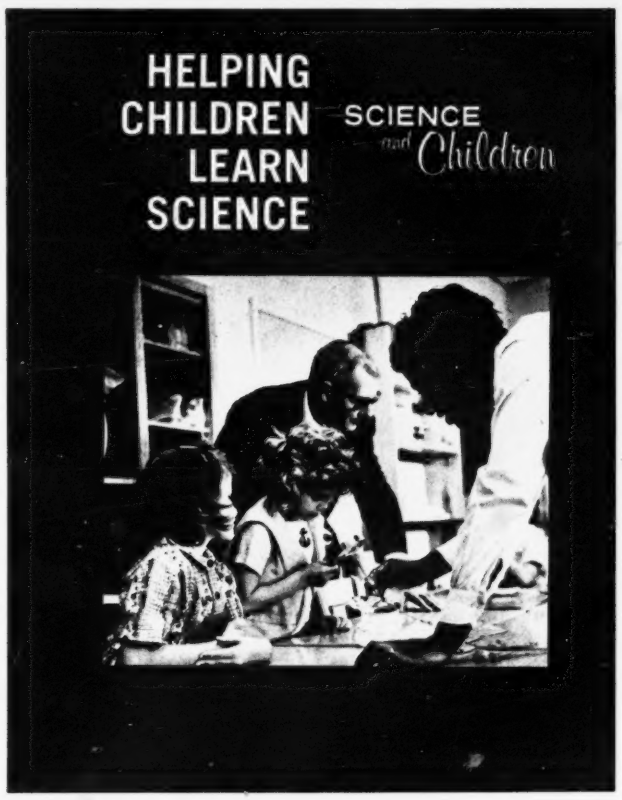

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